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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

DURABILITY OF AGGREGATES

By

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and

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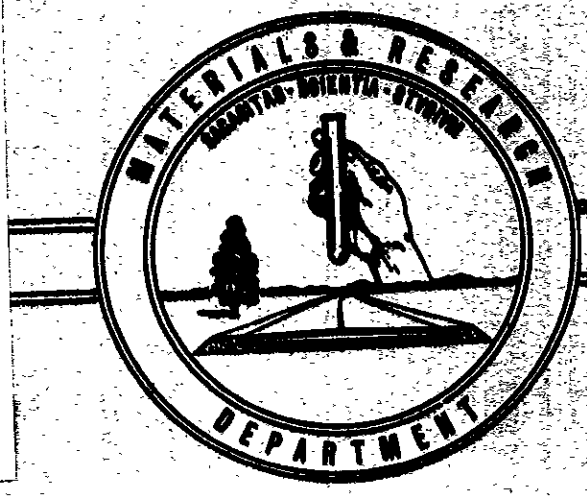

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ABSTRACT

The usual tests used in California to control the quality of aggregates, particularly bases and subbases, are Grading, Specific Gravity, Unit Weight, Absorption, Soundness, Los Angeles Rattler, R-value, Cleanness and Sand Equivalent. A new test called the Durability Index has been developed as a measure of the mechanical durability of aggregates. The test was developed largely as a result of the need for a measure of the breakdown that occurs to aggregates during construction and normal use under traffic conditions. Equipment and procedures used in performing the test are for the most part those used in the Sand Equivalent and Cleanness Value tests.

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Test values on many aggregates from the coast range which are abundant in sandstone, serpentine and shale are low. On the other hand, the aggregates from Southern California show consistently high durability indexes. There is little or no correlation between the Los Angeles Rattler and the Durability Index for the majority of materials tested. This is not surprising when you consider that the two tests measure the results of different abrasion processes. Results of the Durability tests are correlated with behavior based on test results from control and record sampling during the last two years. Correlation of the test results and the known behavior of aggregates in use for many years looks very promising.

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Stones, large and small, have been used for construction purposes for many thousands of years. In more modern times, engineers refer to the smaller sizes under the general term of mineral aggregates. Presumably, this sounds more scientific as it indicates that crushed stone, gravel or sand particles all consist of one or more minerals. Other phrases such as "the enduring stone" convey the idea that solid rock is unchanged by the vicissitudes of time, but both engineers and geologists know that the rocky materials of the earth vary greatly in their ability to withstand the elements or to resist abrasive forces.

The money spent for mineral aggregates represents a large portion of the total money spent for construction, whether for buildings, dams or highway pavements and structures. A check of our records indicates that between one-fifth and one-third of the funds expended for construction of highways in California is for the procurement and placement of aggregates; hence, with a budget of approximately 300 million dollars

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for major construction during the fiscal year, this would result in 60 to 100 million dollars for aggregates on state highway projects alone.

The production, processing, testing and control of aggregates is an ever present consideration in providing better highways for the traveling public. The complexity of the problems connected with aggregate production is increased by the depletion of the best and most convenient sources; by the necessity for considering beneficiation processes in aggregate production; and by the ever present desire to secure good quality aggregates and at the same time keep the cost within reasonable limits.

On the whole we might say that the producer prefers an aggregate that is easily and economically produced; the engineer likes for it to have ideal properties and structural characteristics; and the one who pays the bill wants it to be cheap and last forever.

The usual tests to control the quality of aggregates in California are grading, specific gravity, unit weight, absorption, soundness, Los Angeles rattler, R-value, cleanness, and sand equivalent. Generally, not all of these tests are applied to any one aggregate product. These tests are used on the premise that they will control the quality, suitability, and usefulness of the aggregate as well as these same attributes of the finished product that is produced from the aggregates.

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Both the producer and the user are concerned with a characteristic of the aggregate that may be best described as "durability." Durability means in the broad sense the ability of the aggregate to remain unchanged over a fairly long period of time in spite of adverse natural processes or forces to which it is subjected. Specifically, the term durability as used in this paper means the ability to resist breaking down or grinding up into finer particles.

As an indication of the concern over durability of aggregates, the states of Washington, Oregon and Idaho have in recent years started using specific tests to measure this property of aggregates. Many other public and private agencies are concerned with this problem and have considered or taken steps to assure more durable aggregates.

Considerable work has been done throughout the world in an attempt to develop a test method which will evaluate the resistance of aggregates to mechanical degradation. One of the earliest devices was the Deval Abrasion Test developed in France and, incidentally, a Deval tumbler was the first piece of testing equipment set up in the laboratory of the California Division of Highways in 1912. Probably the most widely used today is the Los Angeles Rattler which was developed about 1925. There have been various types of impact tests, use of laboratory rollers, piston type crushing tests, et cetera. However, while these various test methods will break down or tend to pulverize rock particles under test, it is evident that the fine material

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produced generally differs markedly in character from the fines which result from normal degradation on a roadbed. We have been fairly successful in reproducing characteristic types of fines and aggregate breakdown in the laboratory through the use of the kneading compactor on samples containing considerable amounts of water. However, this type of laboratory determination requires considerable time and rather expensive equipment.

There have been a few clear-cut examples of failure or serious distress in California highways that could be attributed to deterioration or lack of durability of the aggregates. There have been other cases where breakdown of the aggregates was suspected as the cause of trouble but convincing proof is difficult to secure. Unless the entire operation is subjected to close control and frequent tests, a question always arises when excess fines are found; that is, were the fines introduced at the time of construction or did the aggregate lack the ability to withstand abrasive action and the subsequent weathering?

Probably most highway engineers can cite an example of aggregates that met specifications when placed in a stockpile but when these aggregates were incorporated in construction weeks or months later they would not meet the specifications. Again suspicions always arise as to whether the aggregates really met the specifications initially and subsequently degraded, i.e., did the aggregate lack the necessary durability to withstand the weathering and handling involved.

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The first four figures illustrate degradation or breakdown that can take place in the production and handling of aggregate. Figure 1 shows 1½" x 3/4" stone as it left the plant where it met the cleanness specifications for concrete aggregate. The next three figures show changes in cleanness after successive steps in handling the aggregate. It would not meet the cleanness specifications in the condition shown on Figure No. 4.

The question of durability of aggregates has been emphasized in recent years in highway construction by the progress that has been made toward completion of the Interstate System. As a result of inquiries or investigations by Congressional committees or other agencies into highway construction practices, the question of durability or breakdown of aggregates has been increasingly emphasized. As you are well aware the activities of the Blatnik committee or other similar studies have generally evolved around the question of aggregates compling with specifications. There have been numerous investigations concerning the quality or thicknesses of aggregate layers in place. If an investigation indicates a certain grading or other test characteristic for an aggregate in-place and previous tests indicate different characteristics prior to placing, a logical question is "What changes would normally take place as an aggregate is incorporated into a completed roadway?" We have been well aware of this question, and in order to answer it and at the same time move

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toward a more thorough knowledge of the characteristics of suitable aggregates we have developed a Durability test that will be incorporated in our new standard specifications.

Tables 1 and 2 show grading, sand equivalent, R-value and other data that we secured in our study of durability. One set of data was secured from construction control samples as the various components of the roadway section were constructed. The other set of data was secured from final record samples after the roadway had been completed. Perhaps a third evaluation that we need and may secure to a limited extent could be from tests after these roads have been in service for many years. The above data is not always conclusive since the frequency of sampling is too limited to get good statistical values. Generally the final record samples show a breakdown of the aggregate, i.e., finer gradation and lower R-value and sand equivalent. The data also show that this breakdown can be related to results of the Durability test that we have developed.

It may be noted that some inconsistencies exist in the attached tables, particularly in the average grading analyses between the control and record samples for aggregate subbases. This can probably be best explained by the fact that most subbase control samples were obtained from a windrow, and it could not be established with any degree of certainty where the material represented by the control sample would be placed and compacted on the roadbed. This, coupled with the probability

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of segregation during placing and grading variations in each load of material, may account for those data showing a coarser grading in the record sample than was found in the control sample. Since most of the base control samples were obtained immediately after being deposited on the roadbed from a spreader box, a better determination of the actual location of the material represented by the control sample was obtained.

One of the early phases of our study of this problem was the compaction of aggregate samples and subsequent testing to determine the changes in test characteristics. We compacted aggregates using efforts that were far in excess of that required for normal compaction in order to accelerate the normal breakdown and then tested the resulting materials in order to compare the new characteristics with the former characteristics.

Some of the results of this phase of test research are summarized in Table 3 and illustrated by Figures 5 through 15. Figure 5 shows a summary of the changes in R-value that results from excessive compaction of certain aggregates while Figures 6 through 15 show test data comparing actual degradation occurring between control and record samplings with the same material when degraded in our laboratory. It should be noted that, although a somewhat higher degree of particle breakdown was achieved in compacting the material in the laboratory, particularly in the finer sizes, the general shape of the grading curves compares favorably with those of the field sample.

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An interesting relationship is indicated by examining the sand equivalent values of the control samples compared to those values on the same materials sampled from the road after compaction, i.e., final record samples. Examination indicates that those materials having lower values in the durability test are most likely to show the greatest reduction in the sand equivalent values as a result of handling and processing. These relationships are indicated by Figure 16. It appears that if the durability index is known and the initial sand equivalent at the production plant is determined, it will then be possible to predict with considerable assurance the sand equivalent of the final record samples taken from the roadbed and hence the probable R-value range which may be anticipated. This chart also illustrates the well-known fact that sand equivalent values in the neighborhood of 20 correlate very poorly with the R-value measurement. In other words, if sand equivalent values are 35 or better, high R-values are virtually assured. If the values are less than 15, it is practically certain that R-values will be low but with values between 15 and 35, R-values might fall anywhere.

In our study of the problem of durability of aggregates our investigation has covered many areas, and we will not burden you with some of the details or description of the avenues that we ultimately abandoned. While it is evident that the question of durability involves mechanical breakdown, natural weathering processes, chemical action, and probably

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other factors, the Durability test that we have developed reflects primarily the mechanical breakdown of aggregates. We define the durability index as a value indicating the relative resistance of an aggregate to producing detrimental clay-like fines when subjected to the prescribed mechanical methods of degradation.

Our durability test method, which is given in the attached appendix, utilizes for the most part equipment developed for other tests that we were already using, namely, sand equivalent and cleanness. Although the attached Method of Test for Durability of Aggregates uses the term "durability factor" to designate the values obtained in this test, this term is being changed to "durability index" to differentiate from the "durability factor" obtained in freeze-thaw testing of concrete. Durability indexes for either coarse (D_c) or fine (D_f) aggregates may range from 90 for such hard materials as quartz down to 5 or less on clay bound sandstones and shales. In our new standard specifications durability indexes above 35 will be required for Class II and III bases and above 40 for Class I bases and permeable materials. In aggregates containing both coarse and fine fractions we expect to require that the durability index for both sizes must be above the required minimum. It should be emphasized that the durability test (by starting with a washed aggregate in the test sample) measures the quality of the product generated from interparticle abrasion during the agitation period. The fines in

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the original sample have no effect on the durability index. It is not presently anticipated that the durability test will be regularly specified for concrete aggregates or aggregates for asphalt surfacing.

Figures 17 to 20 show the results of numerous durability tests that have been made on aggregate sources from the various regions throughout the State. It will be noted that some areas have many sources that are low or marginal. Test values on many aggregates from the coast range, which are abundant in sandstone, serpentine and shale are very low. On the other hand, the aggregates from Southern California show consistently high durability indexes.

Figure No. 21 shows a grouping of test results by types of mineral aggregate and their corresponding durability indexes. It will be noted that some types of mineral aggregates generally show high test results where other types of mineral aggregates will show low test results. The higher test values were obtained on andesites, granites, and limestones; whereas, the lower test values were obtained on sandstones and weathered volcanics. It should be noted that many of our aggregates are of such a heterogeneous nature that it is difficult, if not impossible, to place them in the categories shown on this chart.

Figure No. 22 shows the relationship between the Los Angeles Rattler and the new durability test. The ordinate shows durability indexes for both the coarse and fine aggregate portions, while the abscissa values show the Los Angeles Rattler loss at 500 revolutions for the coarse materials. It will be

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noted that the very soft materials show up adversely in both tests, but there are certain samples meeting the present Los Angeles Rattler requirements which break down when shaken in water for only ten minutes. It will be observed that there is little or no correlation between the Los Angeles Rattler and the Durability Index for the majority of materials shown on Figure 22. This is not surprising when one considers that the Los Angeles Rattler test results are indicative of the quantity of degradation produced by an abrasion process involving considerable impact while the durability test results reflect the nature of the degraded material that is produced as well as the quantity of degradation by an entirely difference abrasion process.

The question will naturally arise as to what will be the effect of the introduction of this new durability test. Obviously, it will result in the rejection of some sources of aggregate that are presently being used. This is not surprising since some sources of aggregate have been trouble makers in the past and yet a test was not available that would eliminate these sources without the elimination of other known sources of good quality aggregate. It has been somewhat surprising to us to compare the known behavior of aggregate sources with the results of the durability test. The good correlation between behavior and test results has been most encouraging as we have completed the development of this test procedure.

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The new durability test will be used in lieu of the Los Angeles Rattler test on permeable materials and aggregate bases. Since some aggregates would not pass our present specification for the Los Angeles Rattler and these same aggregates will pass the new durability specifications, this will result in a relaxation of our specifications in these instances. The relationship of R-value, grading, sand equivalent and durability in our new specifications for bases will permit the use of some materials under our new specifications that were not acceptable under the present specifications.

It is believed that the introduction of this new durability test will result in two steps toward effective use of aggregates with low or marginal durability characteristics. The quality of these materials can be improved by the use of additives and in many instances this will be the net result. Obviously, this step will usually be taken at the design stage, i.e., designers will propose to use additives with aggregates with low durability factors. Figure No. 23 shows the results of successive durability tests made on several aggregates. You will note that there is a tendency for each durability test to give a higher test value than the preceding test. This is particularly true on aggregates with a low initial durability index. These results point to the beneficial effects of more vigorous washing and manipulating of the aggregates during production. Hence, if a given source has a low durability it may be possible to improve the durability of that particular aggregate source by more vigorous

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processing procedures.

As discussed earlier, this new durability test procedure primarily reflects the breakdown resulting from mechanical manipulation. We will continue to explore the effects of degradation due to other causes such as weathering, chemical action, etc., and hope we can ultimately establish test procedures that will realistically take into account all processes affecting the performance of the material on the road.

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ACKNOWLEDGMENTS

Credit should be given to Mr. C. A. Frazier, Materials and Research Engineering Associate with the California Division of Highways, for his work in the development of the Durability test procedure and the preparation of the data included in this paper. The major portion of the work was under the direction of Mr. A. W. Root, Supervising Materials and Research Engineer, who retired in May 1962.

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TABLE 1

Average Test Results of Control and Record Samples on Aggregate Bases

Contract No.	No. Locations	Control or Record	Average Percentage Passing Designated Sieve Sizes 1½"	3/4"	#4	#30	#200	Avg. Sand Equiv.	Avg. R Value	Durability Index Coarse D_c	Durability Index Fine D_f
61-3T13C15-F	2	C	94	68	34	20	4	50	80	87	86
		R	93	72	38	22	4	50	82		
61-7X13C15-P	3	C	100	98	50	22	7	66	79	80	80
		R	100	99	56	26	9	59	82		
61-6X13C54-F	2	C	100	94	44	23	6	47	76	87	78
		R	100	96	51	28	8	54	82		
61-3T13C31	6	C	97	80	37	15	4	47	80	78	74
		R	98	81	38	16	4	39	82		
61-6X13C52-P	5	C	99	67	40	24	6	66	80	85	70
		R	100	69	42	25	7	58	79		
61-11V13C7-F	3	C	96	75	47	22	10	31	80	66	68
		R	97	73	46	21	9	33	79		
61-10X13C32-P	5	C	91	77	52	24	8	48	79	67	66
		R	93	78	53	25	6	49	80		
62-2T13C2	2	C	96	77	52	22	8	44	81	63	69
		R	98	84	57	25	10	40	82		

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TABLE 1 (Contd.)

Average Test Results of Control and Record Samples on Aggregate Bases

Contract No.	No. Locations	Control or Record	Average Percentage Passing Designated Sieve Sizes 1½"	3/4"	#4	#30	#200	Avg. Sand Equiv.	Avg. R Value	Durability Index Coarse Dc	Durability Index Fine Df
62-10T13C1	3	C	100	95	49	25	7	31	79	59	65
		R	100	94	48	26	7	31	79		
61-4X13C38-P	3	C	100	63	24	11	6	28	81	67	57
		R	100	81	37	17	9	32	80		
61-3TC3	5	C	97	67	38	20	7	40	79	62	57
		R	97	71	41	22	10	40	81		
62-6Y24C3	3	C	96	86	67	30	13	31	79	54	51
		R	97	91	74	31	14	33	80		
61-9X13C12-P	4	C	100	96	51	30	12	37	81	59	48
		R	100	96	55	30	11	44	79		
60-6TC13-FP	5	C	100	96	58	31	9	32	80	59	44
		R	100	96	56	31	8	30	80		
61-1TC6	4	C	96	73	38	15	6	35	81	52	40
		R	98	81	48	22	10	26	74		
60-1DDC15-P	4	C	88	60	25	15	7	24	78	40	43
		R	97	74	39	24	10	25	79		
61-4X13C35-P	1	C	99	81	39	20	5	38	78	35	28
		R	99	85	45	25	9	27	82		

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Table 2

Average Test Results of Control and Record Samples on Aggregate Subbases

Contract No.	No. Locations	Control or Record	Average Percentage Passing Designated Sieve Sizes 1½"	3/4"	#4	#30	#200	Avg. Sand Equiv.	Avg. R Value	Durability Index Coarse D_c	Durability Index Fine D_f
60-3TC37-F	2	C	94	75	42	28	4	68	77	86	85
		R	92	72	39	23	4	60	82		
61-3T13C18	2	C	100	92	76	62	6	75	69	90	81
		R	100	94	76	65	8	68	74		
62-10Y24C01	3	C			100	88	12	39	70	-	79
		R			100	88	15	34	70		
61-1T13C16	2	C	82	62	35	14	3	42	80	73	67
		R	88	69	40	16	4	37	83		
61-3T13C35-F	1	C	63	54	44	28	8	29	80	74	66
		R	52	34	27	18	6	24	80		
62-2T13C2	1	C	85	69	44	20	7	45	81	63	69
		R	95	77	51	27	8	39	83		
60-3TC38	3	C	92	64	42	30	7	37	81	78	62
		R	90	55	35	25	8	29	77		
60-3TC24-FIPD	1	C	96	79	57	39	7	48	81	61	74
		R	96	73	52	34	7	54	76		
61-4X13C39-P	2	C	100	82	38	18	8	38	80	66	52
		R	100	86	48	21	10	36	82		

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Table 2 (Contd.)

Average Test Results of Control and Record Samples on Aggregate Subbases

Contract No.	No. Locations	Control or Record	Average Percentage Passing Designated Sieve Sizes 1½"	3/4"	#4	#30	#200	Avg. Sand Equiv.	Avg. R Value	Durability Index Coarse D_c	Durability Index Fine D_f
60-5VC11-F	3	C				100	12	29	70	-	49
		R				100	13	27	72		
62-10T13C1	2	C	99	92	68	36	6	38	75	48	63
		R	100	93	66	36	6	35	68		
62-11V13C4-F	1	C	100	98	85	34	11	54	77	-	45
		R	100	100	97	46	16	39	74		
61-6X13C51-F	4	C		100	96	49	12	46	71	-	40
		R		100	97	50	14	40	68		
60-5TC10	2	C	100	76	50	22	6	32	76	38	58
		R	100	80	52	24	8	30	79		
61-5X13C26-P	5	C	100	99	93	46	12	50	75	-	35
		R	100	100	94	48	14	39	75		
61-10T13C18	3	C	100	100	100	48	15	58	69	-	30
		R	100	99	98	51	16	44	68		
61-4MBC1	1	C	100	68	27	14	8	22	80	36	28
		R	100	90	52	27	14	23	71		
61-4X13C38-P	2	C	89	56	34	26	9	40	81	13	21
		R	97	80	56	44	16	28	76		

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Table 2 (Contd.)

Average Test Results of Control and Record Samples on Aggregate Subbases

Contract No.	No. Locations	Control or Record	Average Percentage Passing Designated Sieve Sizes 1½"	3/4"	#4	#30	#200	Avg. Sand Equiv.	Avg. R Value	Durability Index Coarse D_c	Durability Index Fine D_f
61-4T13C26-P	10	C	100	88	51	23	10	36	78	12	26
		R	100	92	58	29	12	33	77		
62-2Y24C05-P	2	C	90	77	45	30	16	32	59	8	18
		R	98	89	66	50	27	18	50		

Table 3

Summary of Laboratory Degradation Tests
Using Kneading Compactor
(1000 applications at 290 psi)

Sample No.	Type of Material	Sample Ident.*	Sieve Analysis % Passing 3/4"	#4	#30	#200	SE	R Value	Durability Index D_c	Durability Index D_f
60-2668	Base	T	100	56	30	4	68	82	87	86
		D	100	52	33	9	37	75		
60-2666	Subbase	T	100	61	29	5	-	-	86	85
		D	100	61	29	5	73	79		
61-4238	Subbase	T	100	99	90	5	78	58	-	81
		D	100	99	88	9	66	73		
62-3177	Base	T	100	45	22	6	49	83	87	78
		D	100	48	27	8	37	83		
61-1400	Base	T	100	51	20	5	43	79	78	74
		D	100	55	25	9	30	77		
61-4332	Base	T	100	54	27	7	67	80	78	74
		D	100	58	33	10	59	81		
61-4116	Base	T	100	97	56	21	29	74	-	73
		D	100	97	60	21	26	71		
61-3819	Subbase	T	100	60	24	5	46	-	73	67
		D	100	63	31	9	28	84		
62-3228	Base	T	100	58	29	10	37	83	73	67
		D	100	66	40	20	23	68		
61-3567	Base	T	100	56	36	13	40	81	65	78
		D	100	62	46	19	27	84		
60-3358	Subbase	T	86	56	36	9	42	82	78	62
		D	86	57	39	13	26	80		
61-4335	Base	T	100	49	28	10	25	81	76	62
		D	100	50	31	13	23	79		
62-3284	Base	T	100	41	19	10	34	84	67	57
		D	100	48	29	17	22	80		

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Table 3 (Contd.)

Summary of Laboratory Degradation Tests
Using Kneading Compactor
(1000 applications at 290 psi)

Sample No.	Type of Material	Sample Ident.*	Sieve Analysis % Passing 3/4"	#4	#30	#200	SE	R Value	Durability Index D_c	D_f
61-1245	Subbase	T	100	97	49	15	44	71	-	35
		D	100	98	59	22	26	64		
60-2799	Base	T	100	46	16	8	34	79	40	33
		D	100	56	24	14	22	79		
62-2933	Subbase	T	100	58	15	4	52	81	38	33
		D	100	68	29	14	32	80		
62-4171	Base	T		100	77	31	35	78	40	31
		D		100	84	53	15	67		
62-1003	Base	T	100	51	24	8	30	80	29	29
		D	100	71	49	28	15	22		
61-1044	Base	T	100	48	24	6	39	84	35	28
		D	100	92	70	35	17	27		
61-2861	Subbase	T	100	34	16	7	32	82	26	27
		D	100	51	30	15	28	66		
61-2431	Subbase	T	100	67	39	20	24	56	27	26
		D	100	79	55	32	19	26		
62-3064	Subbase	T	100	72	49	25	19	57	43	25
		D	100	76	50	27	16	47		
62-1691	Subbase	T	100	45	22	12	22	82	23	24
		D	100	78	54	36	13	11		
61-5058	Base	T	100	36	16	8	24	79	22	28
		D	100	17	32	16	17	53		
61-5445	Subbase	T	100	31	11	7	30	81	20	25
		D	100	61	35	21	17	25		
61-3963	Subbase	T	100	43	10	7	33	80	19	26
		D	100	86	54	34	16	46		
61-843	Subbase	T	100	51	22	8	25	48	16	18
		D	100	80	54	38	13	8		

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Table 3 (Contd.)

Summary of Laboratory Degradation Tests
Using Kneading Compactor
(1000 applications at 290 psi)

Sample No.	Type of Material	Sample Ident.*	Sieve Analysis % Passing 3/4"	#4	#30	#200	SE	R Value	Durability Index Dc	Df
61-624	Base	T	80	37	21	7	37	81	62	57
		D	86	44	26	11	28	81		
61-3101	Base	T	100	60	28	13	29	83	57	62
		D	100	65	35	18	22	81		
62-4144	Subbase	T	100	70	42	18	34	81	52	50
		D	100	87	64	40	17	52		
61-1199	Subbase	T			100	12	28	65	-	49
		D			100	14	26	65		
61-4459	Subbase	T	100	97	39	11	47	-	-	45
		D	100	99	48	15	43	77		
61-1231	Base	T	100	46	21	6	34	79	59	44
		D	100	55	29	11	27	78		
62-1679	Base	T	100	42	21	10	-	-	48	43
		D	100	51	29	16	26	80		
61-3851	Base	T	100	51	18	4	42	80	48	41
		D	100	67	37	18	20	70		
60-2919	Base	T	88	48	19	7	37	82	52	40
		D	92	54	26	13	23	73		
61-1365	Subbase	T		100	50	14	43	71	-	40
		D		100	56	24	23	48		
61-3007	Base	T	100	38	24	11	27	81	40	43
		D	100	53	36	15	23	80		
60-3408	Subbase	T	100	66	28	8	35	73	38	58
		D	100	69	30	10	32	78		
61-506	Subbase	T	100	78	54	26	22	71	42	38
		D	100	79	56	32	16	42		
62-1685	Base	T	100	52	16	4	62	82	36	47
		D	100	58	25	10	31	83		

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Table 3 (Contd.)

Summary of Laboratory Degradation Tests
Using Kneading Compactor
(1000 applications at 290 psi)

Sample No.	Type of Material	Sample Ident.*	Sieve Analysis % Passing 3/4"	#4	#30	#200	SE	R Value	Durability Index D_c	Durability Index D_f
61-2788	Subbase	T	100	43	21	7	31	78	15	22
		D	100	87	60	31	20	30		
61-5444	Subbase	T	100	45	27	14	19	58	14	24
		D	100	74	61	37	11	30		
61-1483	Subbase	T	100	60	46	16	39	79	13	21
		D	100	93	80	33	19	43		
60-3950	Subbase	T	90	62	25	9	53	79	12	26
		D	95	69	41	21	21	54		
61-4154	Subbase	T	100	55	36	21	29	68	8	18
		D	100	83	69	50	14	43		
61-5123	Subbase	T	100	33	11	5	28	76	2	26
		D	100	72	44	24	8	56		

*T = Values as used
D = Values after laboratory compaction

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1½" x 3/4" primary size of concrete aggregate sampled from truck after loading at producer's plant - Cleanness Value 82.

Material sampled from truck after hauling approximately 25 miles to concrete batch plant - Cleanness Value 77.

Material sampled from conveyor belt just prior to dropping into storage bin at batch plant.

Sample of same material as discharged from weigh hopper at batch plant - Cleanness Value 47.

FIGURE 5

REDUCTION IN R-VALUE AFTER LABORATORY DEGRADATION

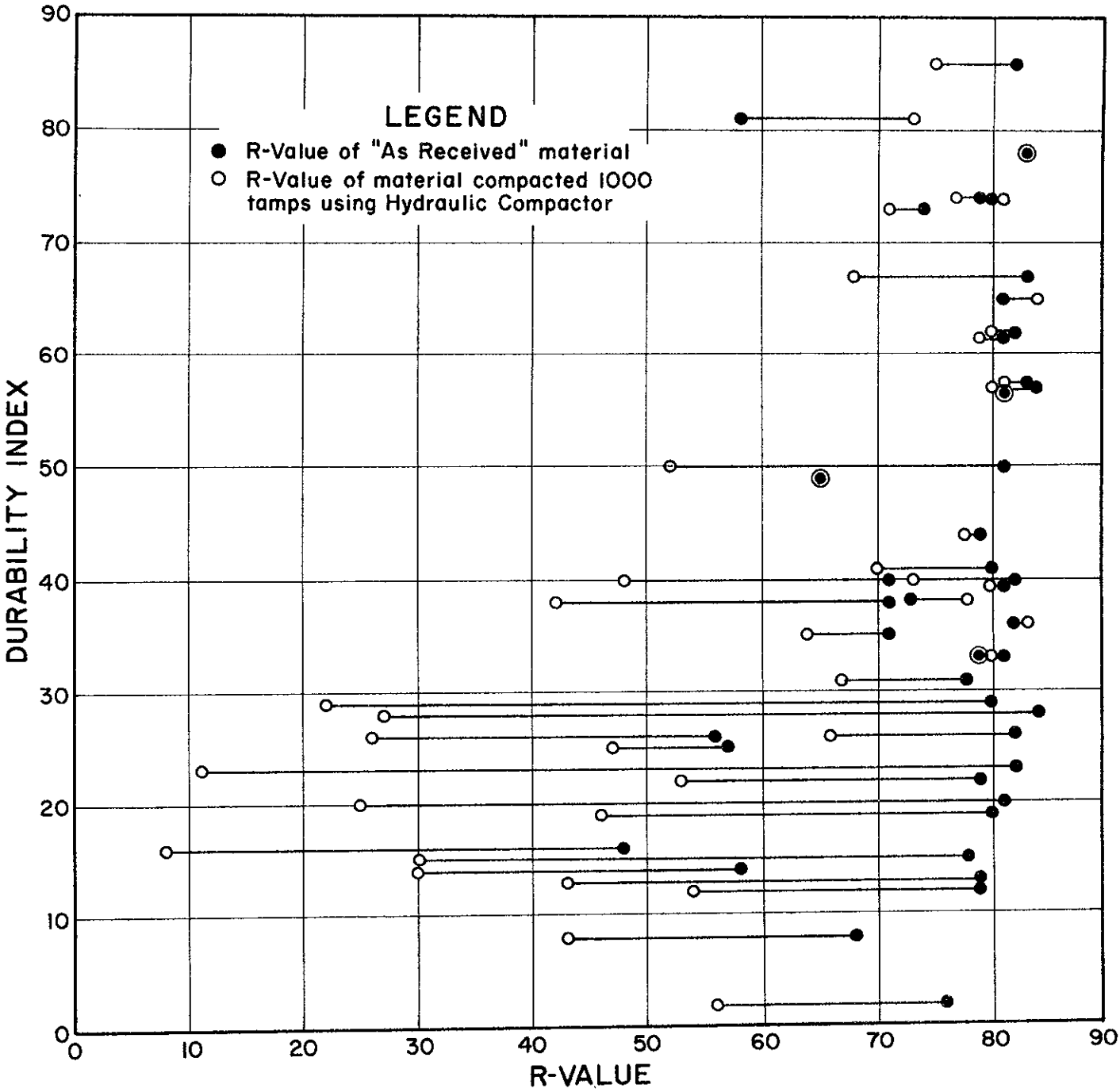

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FIGURE 6

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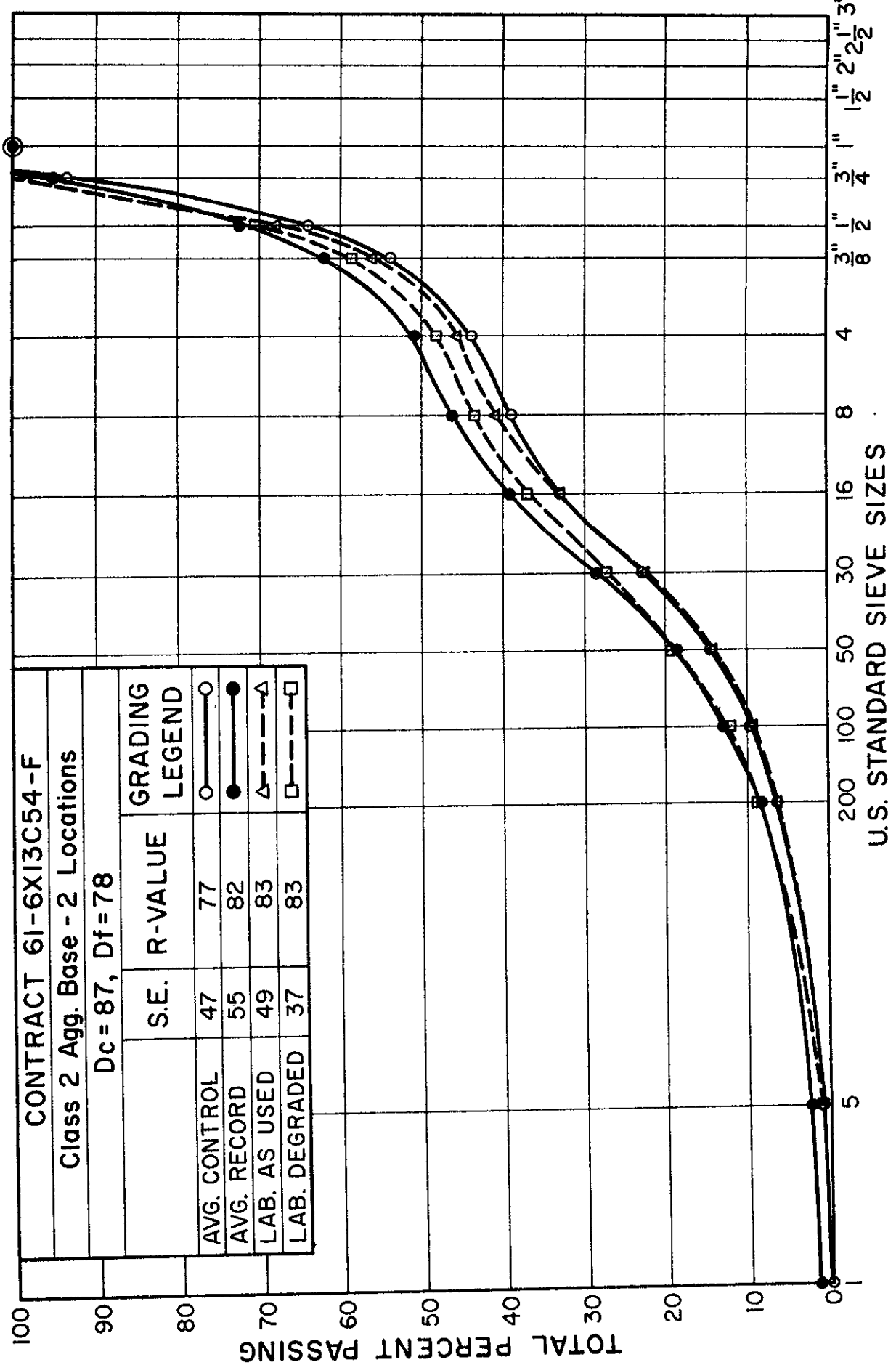
GRADING ANALYSIS



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GRADING ANALYSIS

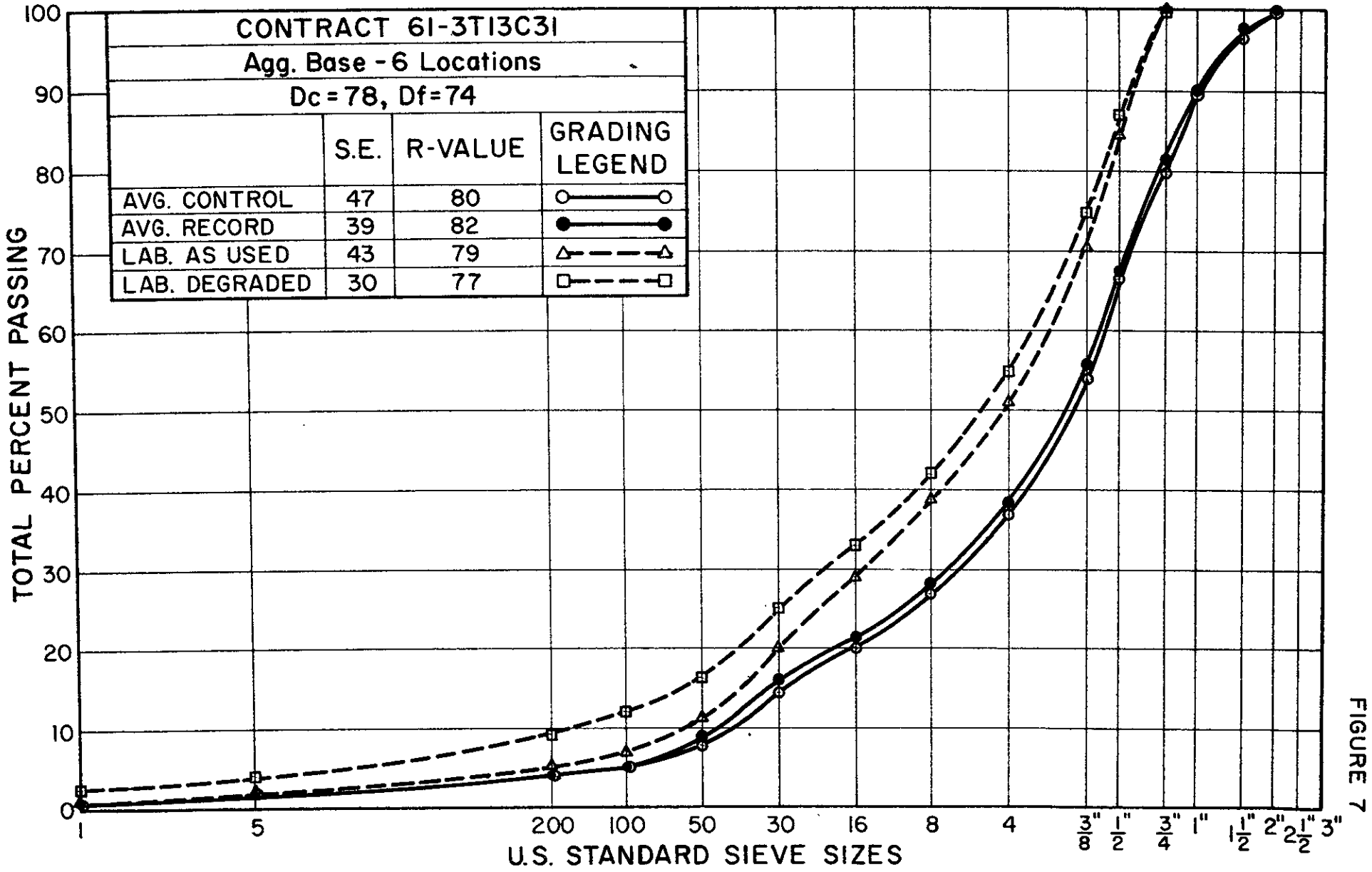

FIGURE 7

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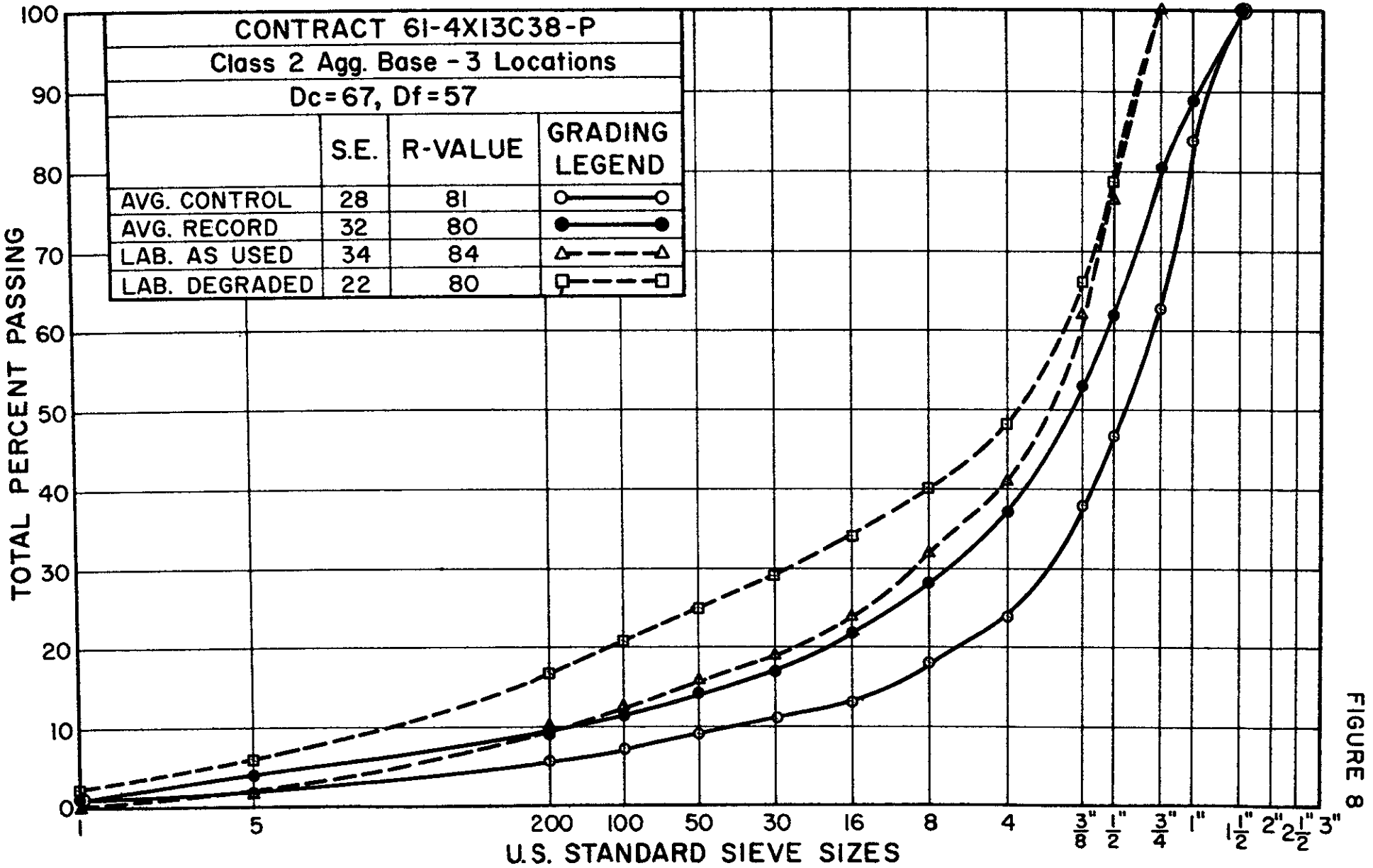

FIGURE 8

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GRADING ANALYSIS

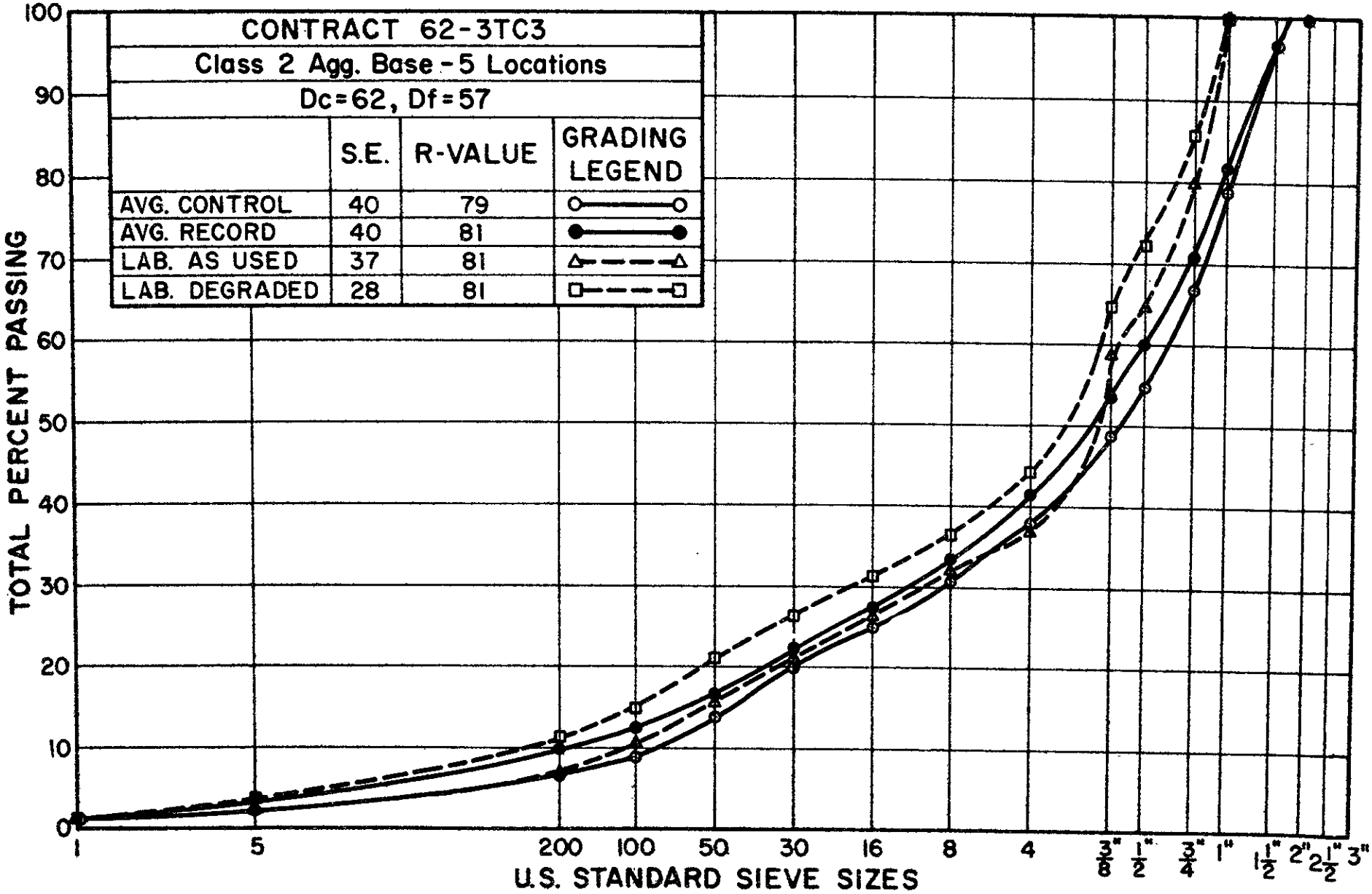

FIGURE 9

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GRADING ANALYSIS

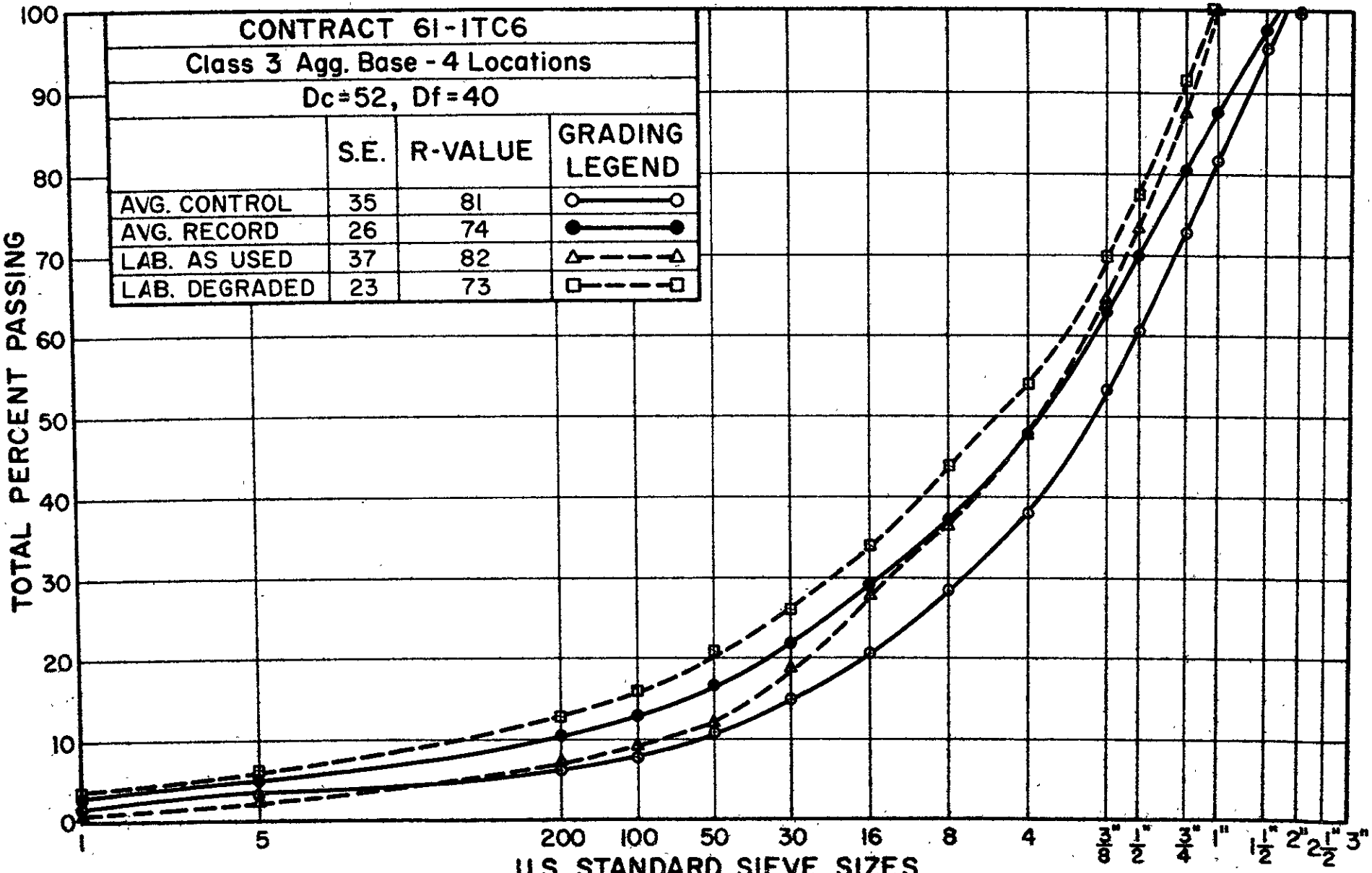

FIGURE 10

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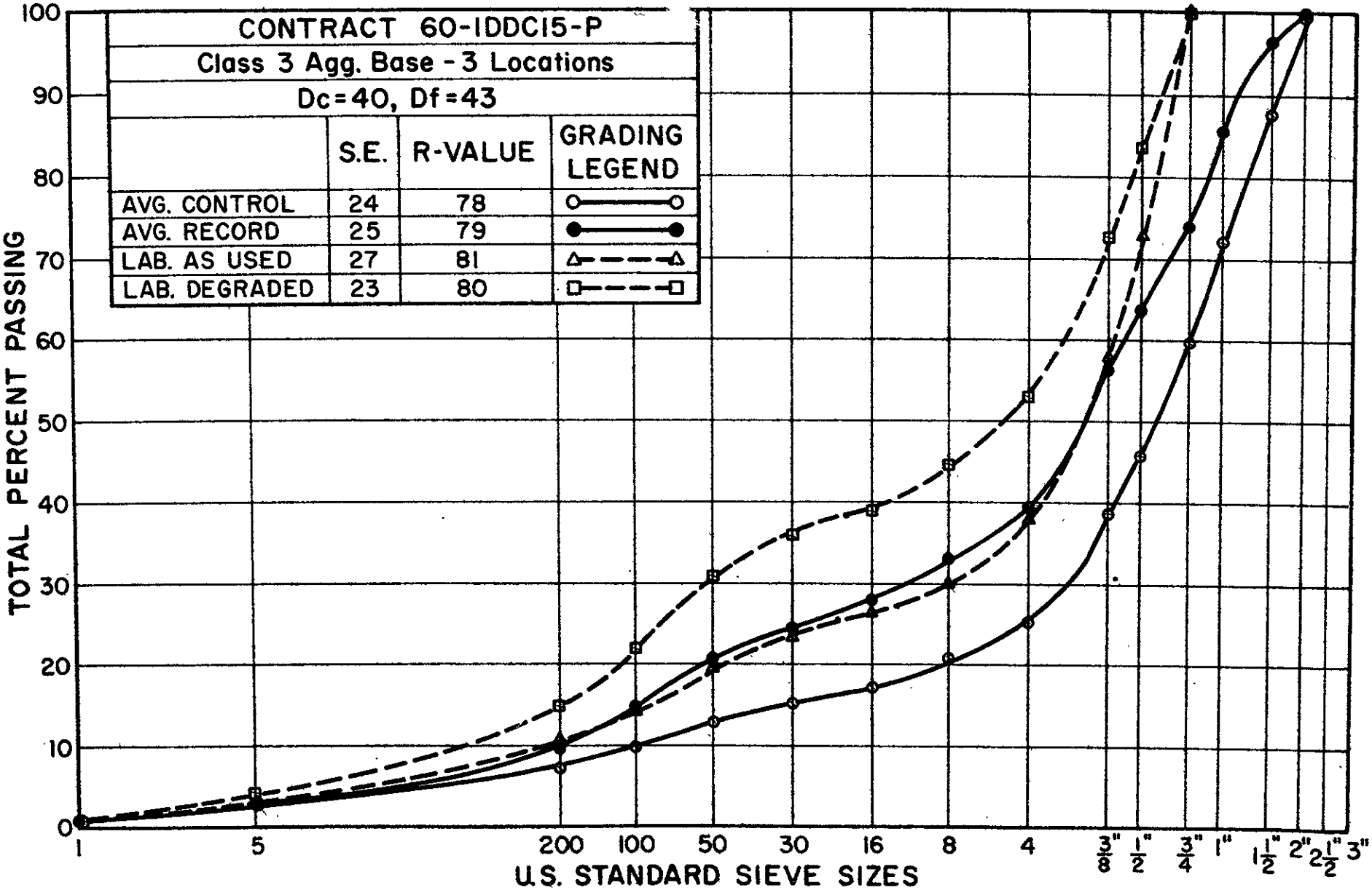

FIGURE 11

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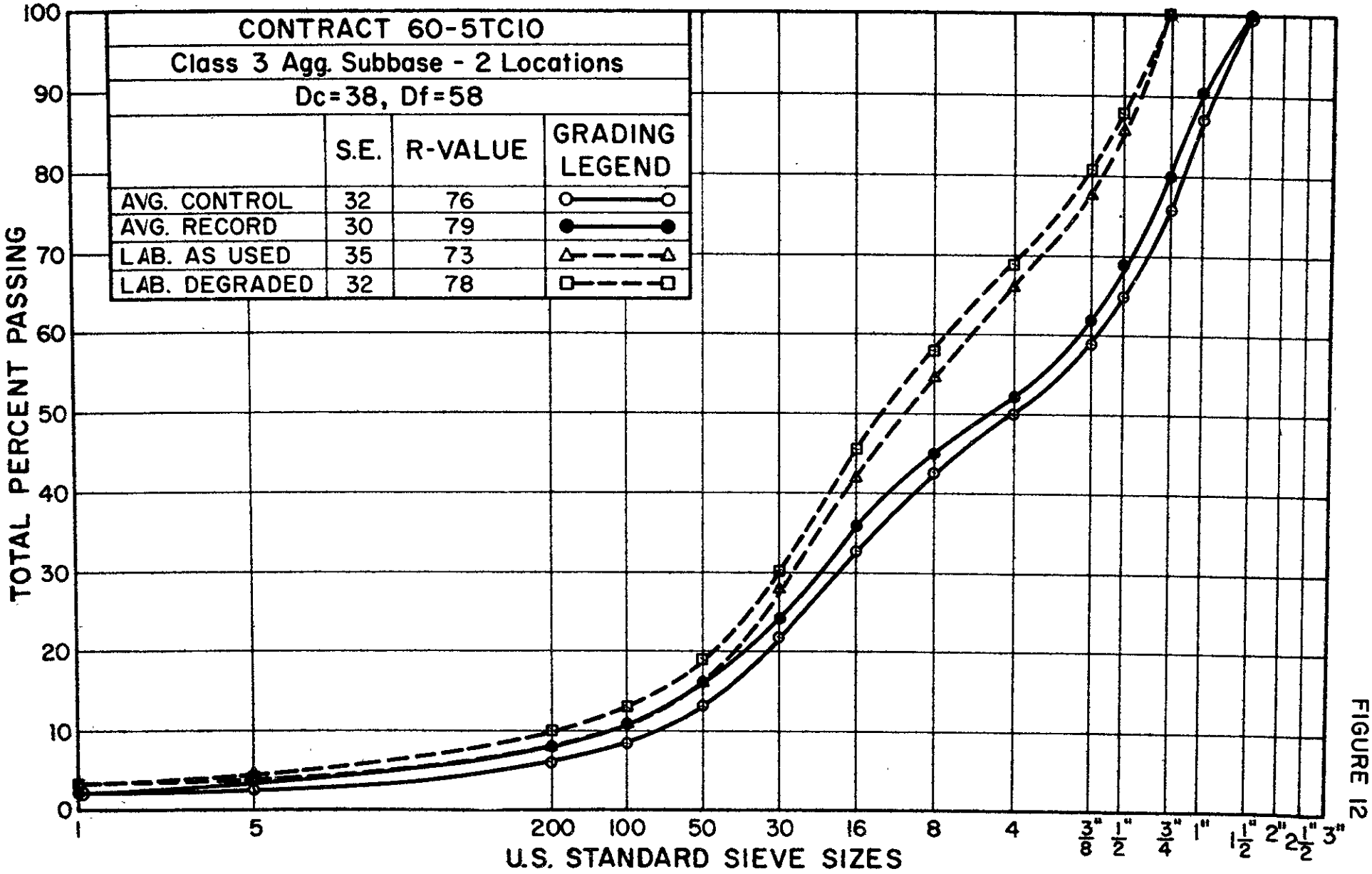

FIGURE 12

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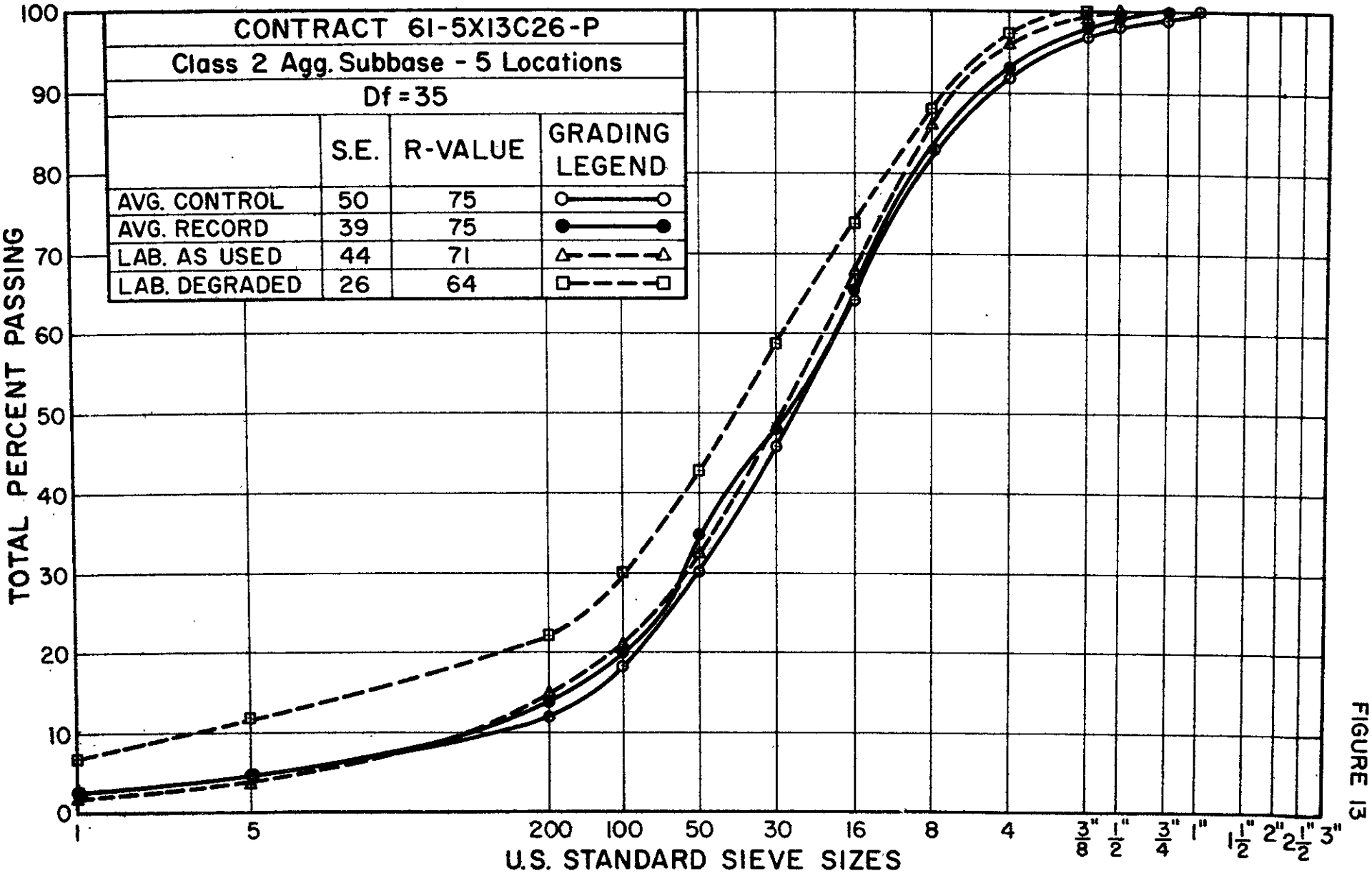

FIGURE 13

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GRADING ANALYSIS

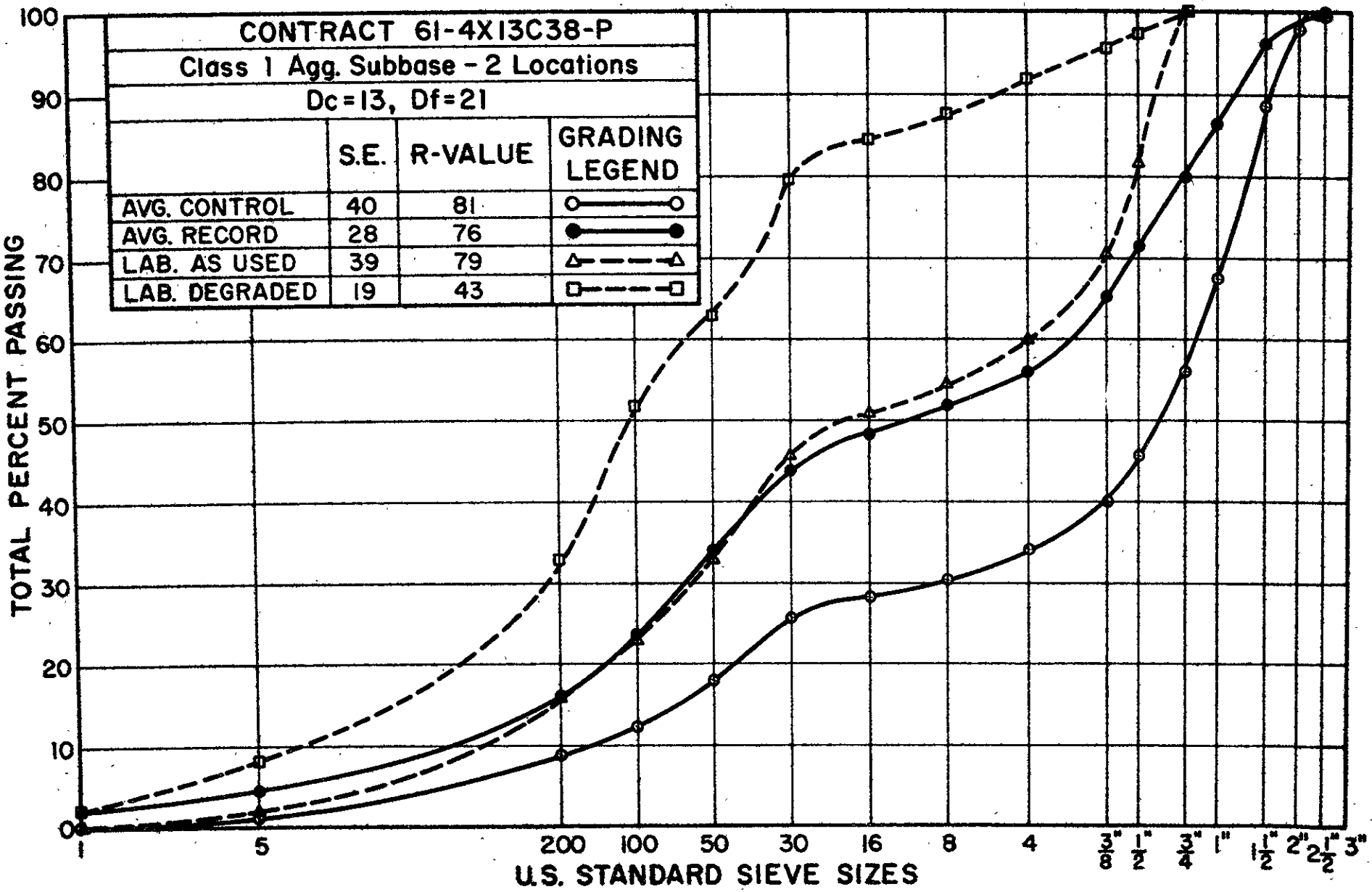

FIGURE 14

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GRADING ANALYSIS

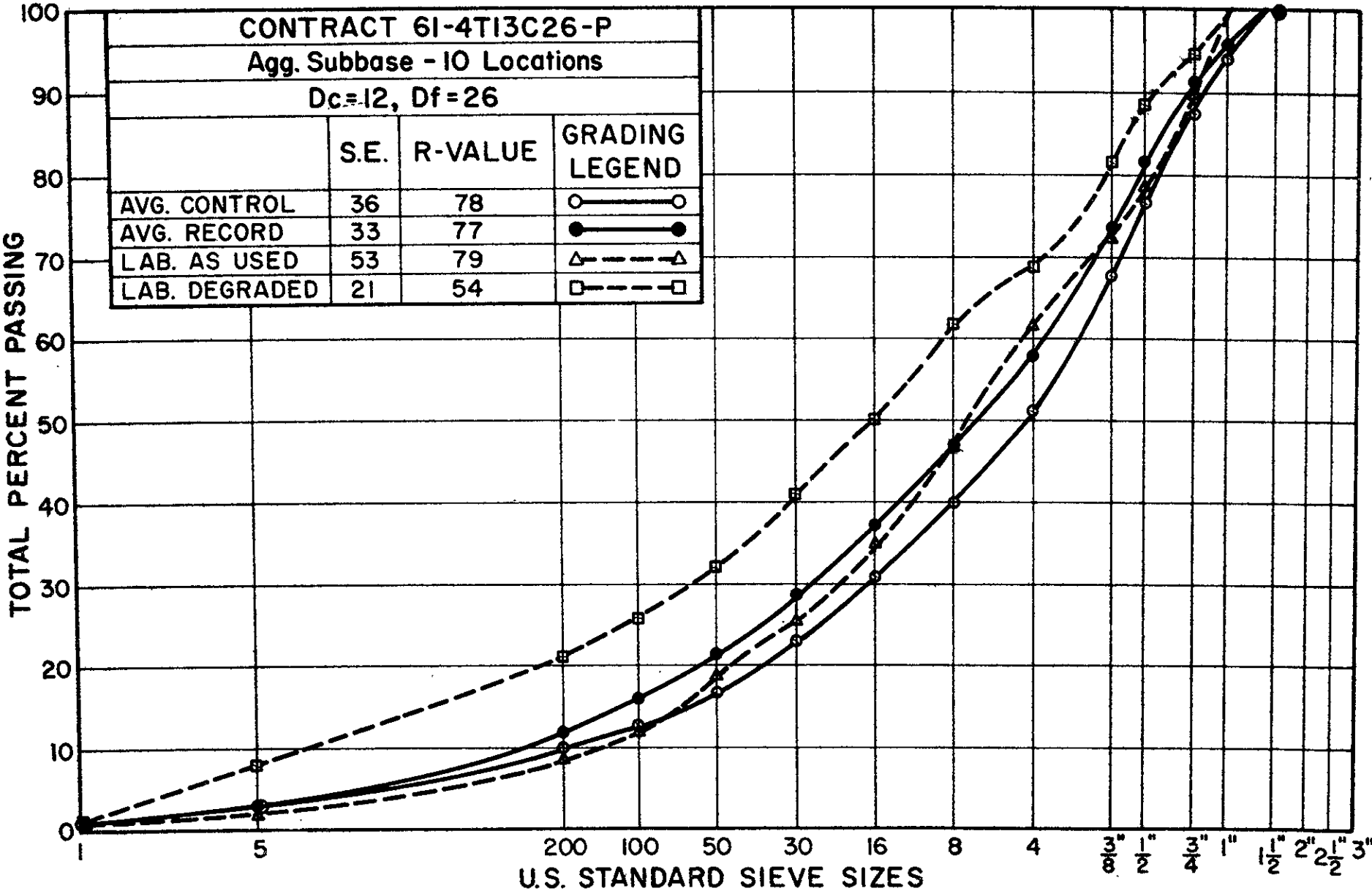

FIGURE 15

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CHART INDICATING CERTAIN INTERRELATIONSHIPS BETWEEN SAND EQUIVALENT-DURABILITY INDEX AND R-VALUE

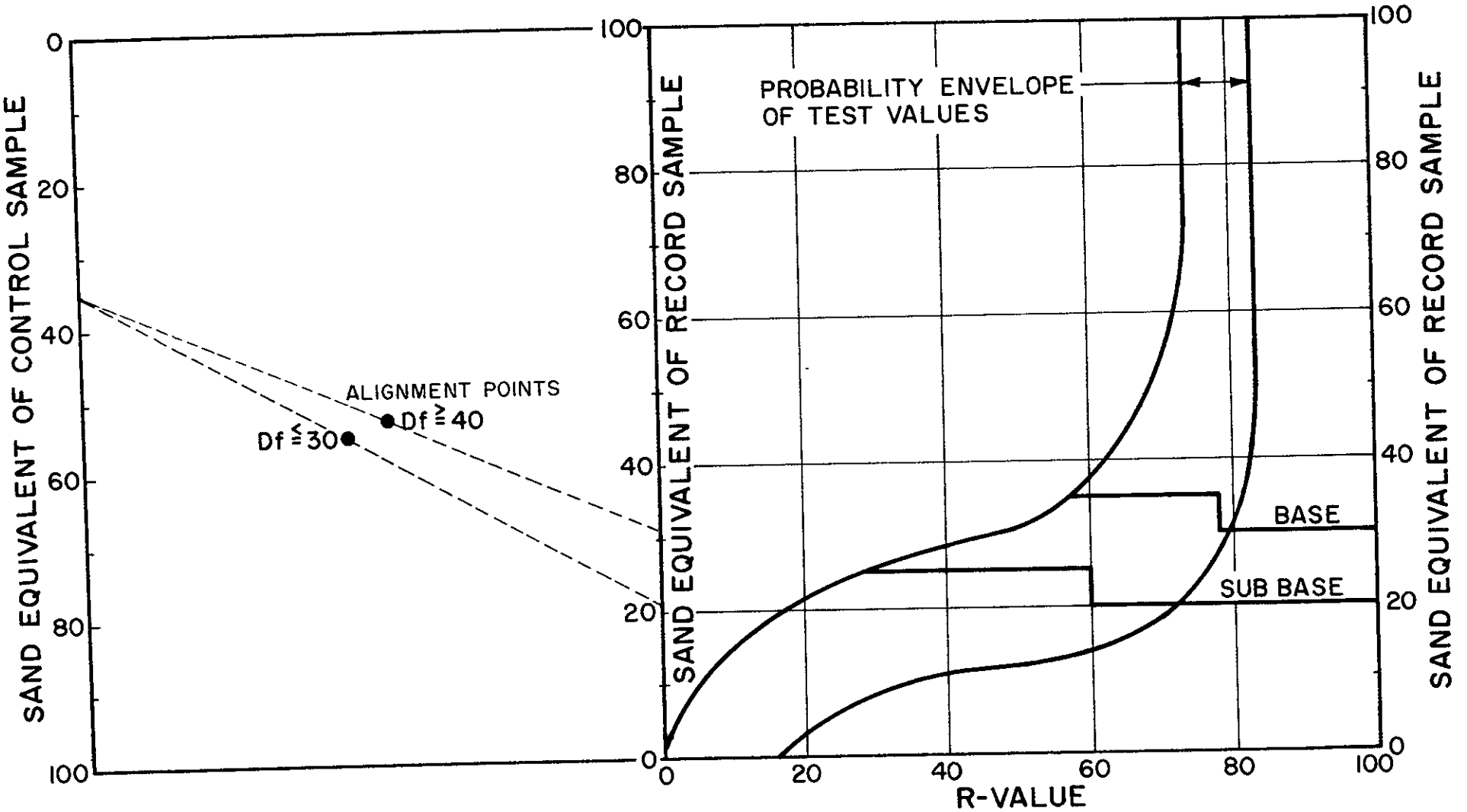

FIGURE 16

FIGURE 17

FREQUENCY DISTRIBUTION OF DURABILITY INDEXES

CALIFORNIA COAST RANGES

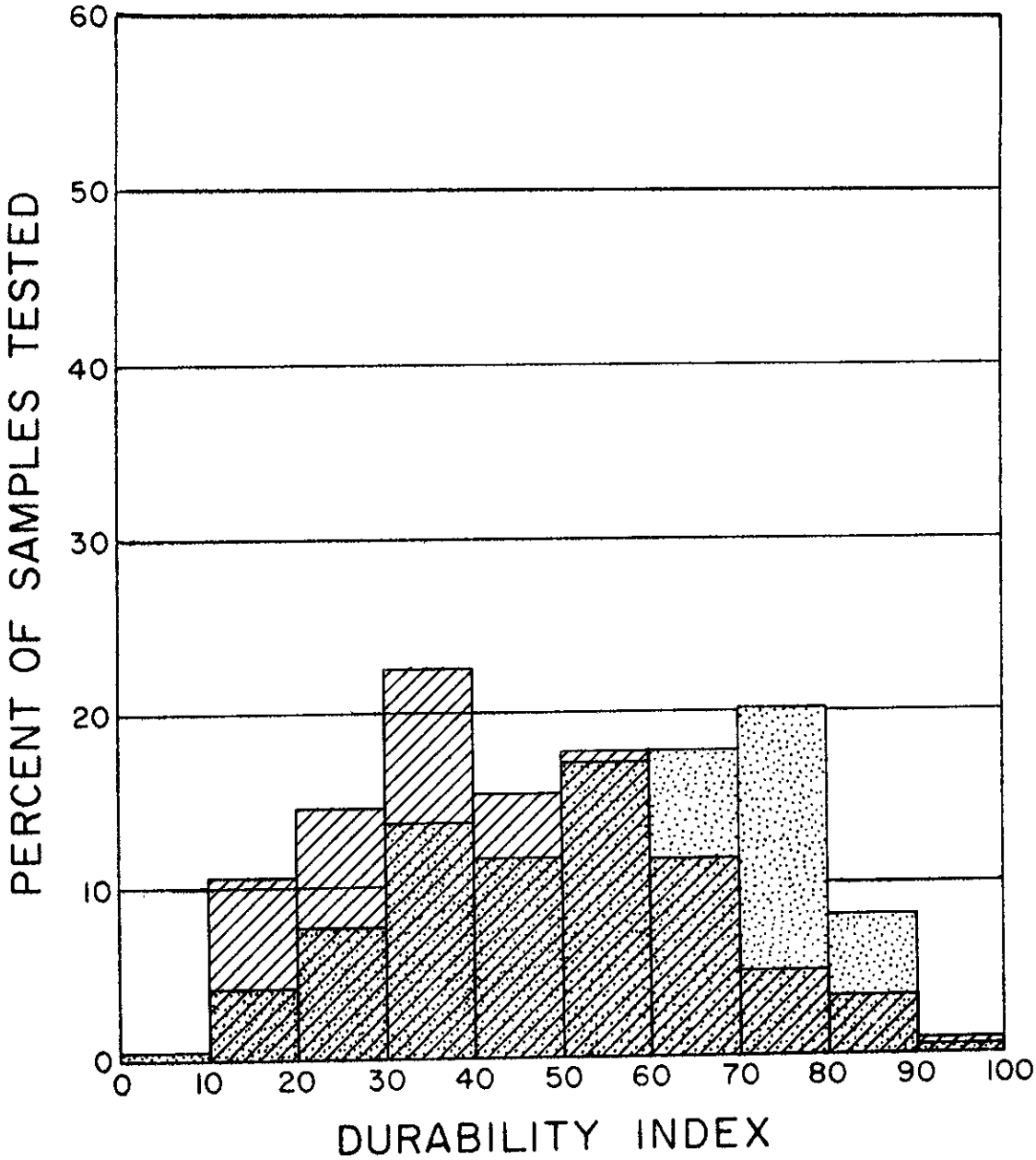

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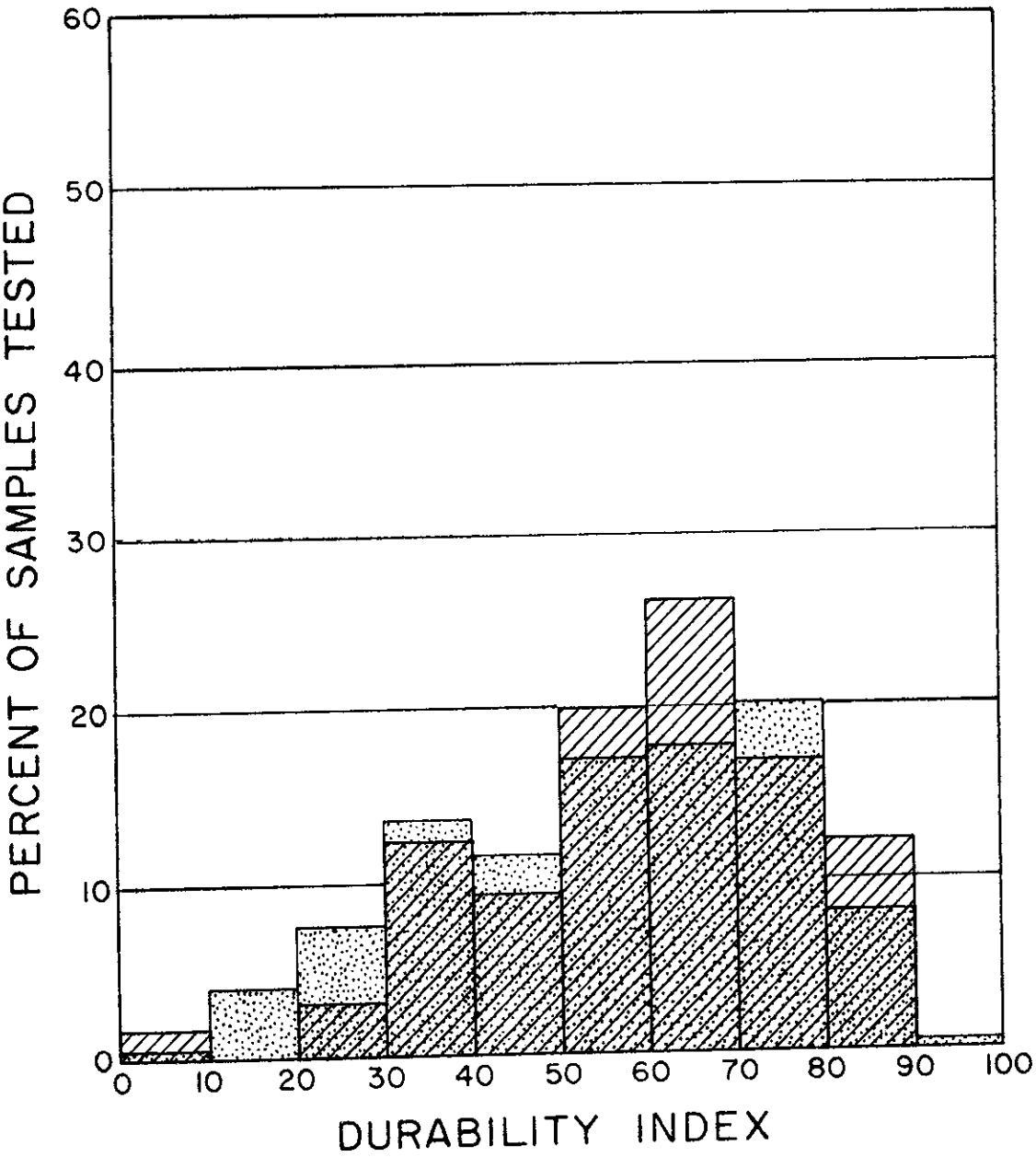
FIGURE 18

FREQUENCY DISTRIBUTION OF DURABILITY INDEXES

NORTHERN CALIFORNIA



NORTHERN CALIFORNIA — 66 Samples

CALIFORNIA — 323 Samples

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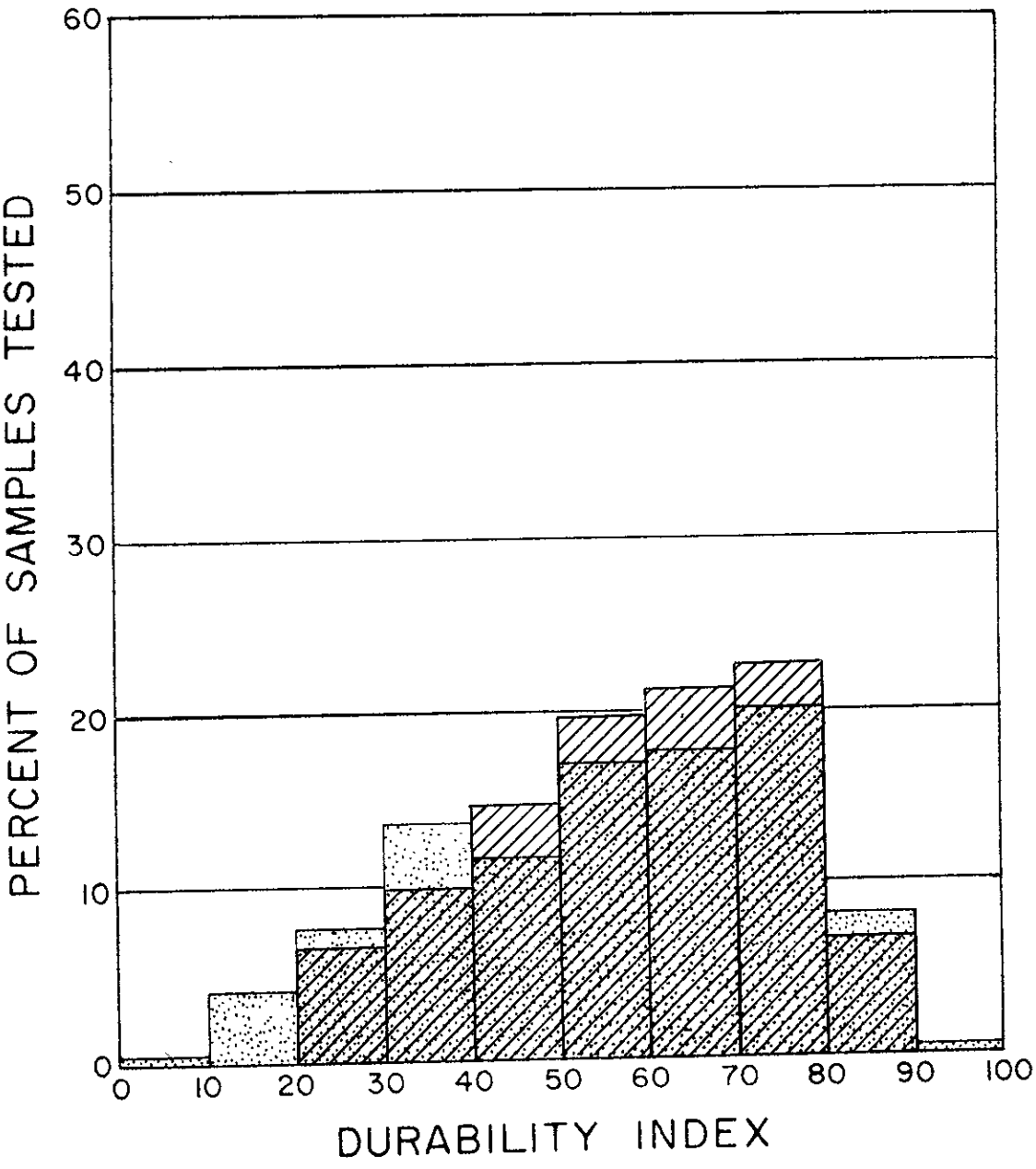
FIGURE 19

FREQUENCY DISTRIBUTION OF DURABILITY INDEXES

CENTRAL CALIFORNIA



CENTRAL CALIFORNIA — 62 Samples

CALIFORNIA — 323 Samples

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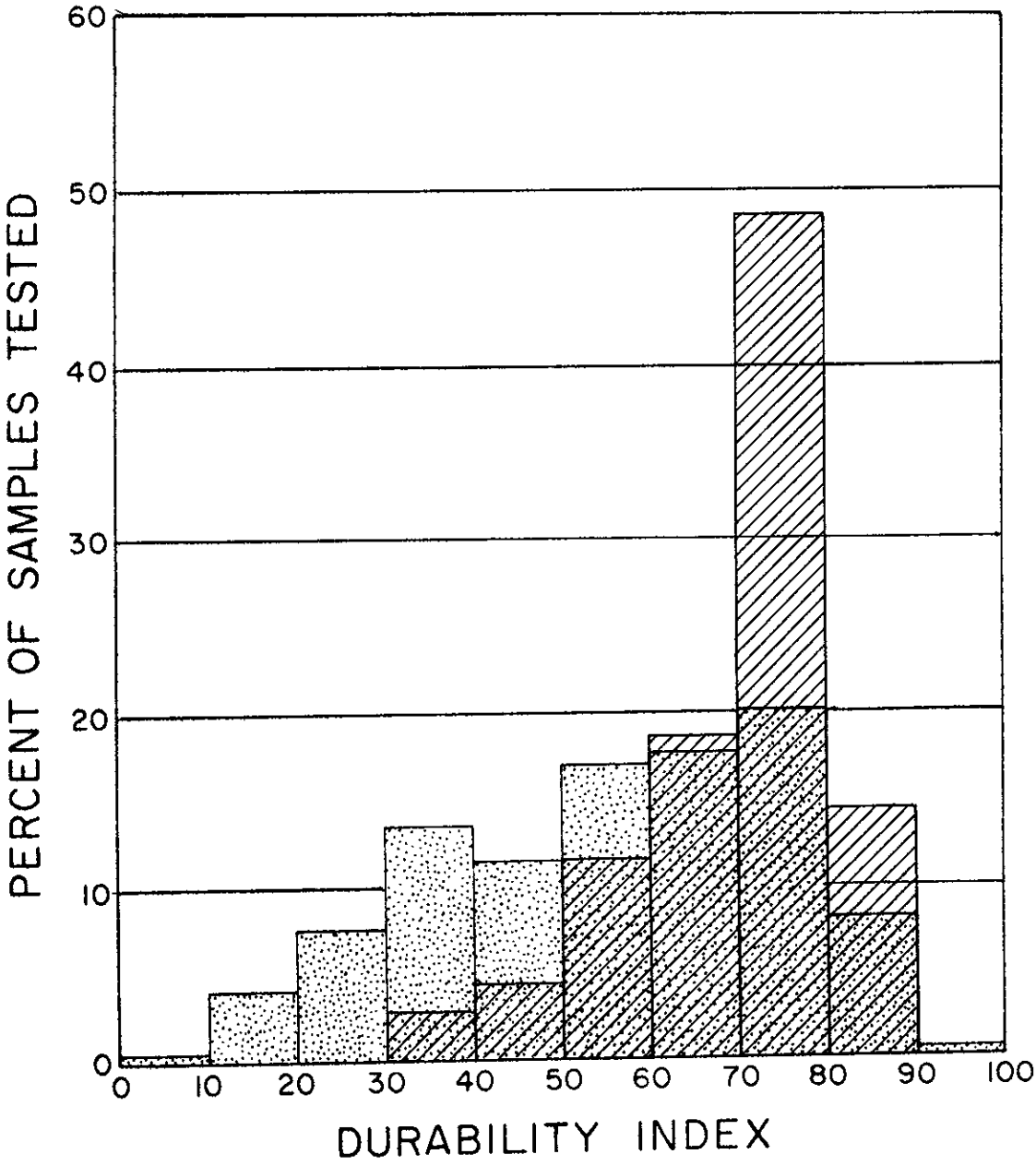
FIGURE 20

FREQUENCY DISTRIBUTION OF DURABILITY INDEXES

SOUTHERN CALIFORNIA



SOUTHERN CALIFORNIA — 70 Samples

CALIFORNIA — 323 Samples

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FIGURE 21

DURABILITY VERSUS PETROGRAPHIC CLASSIFICATION OF STONE

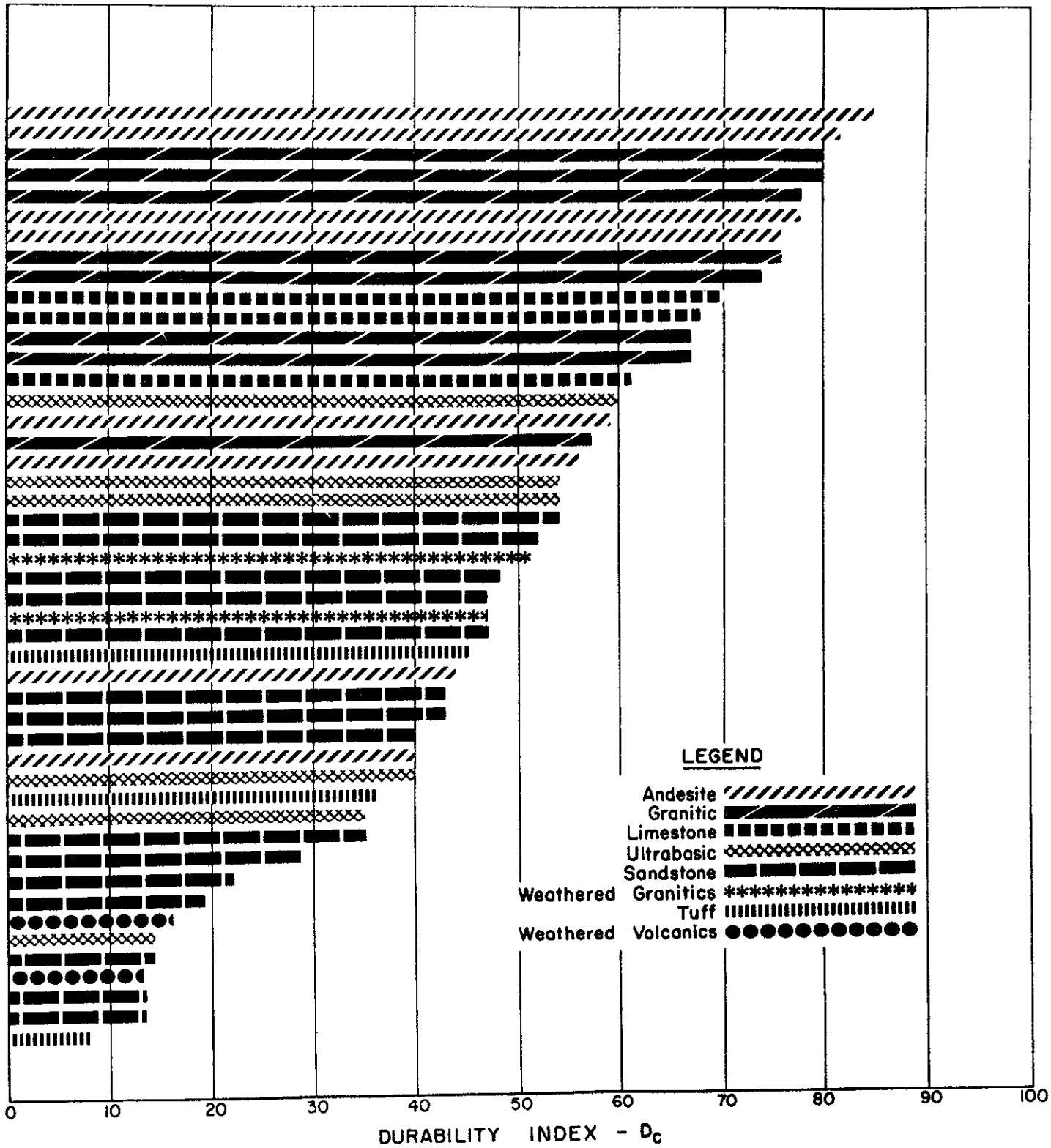

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FIGURE 22

CHART SHOWING COMPARISON BETWEEN LOSS AT 500 REVOLUTIONS IN L.A. RATTLER AND DURABILITY INDEXES ON COARSE AND FINE AGGREGATES

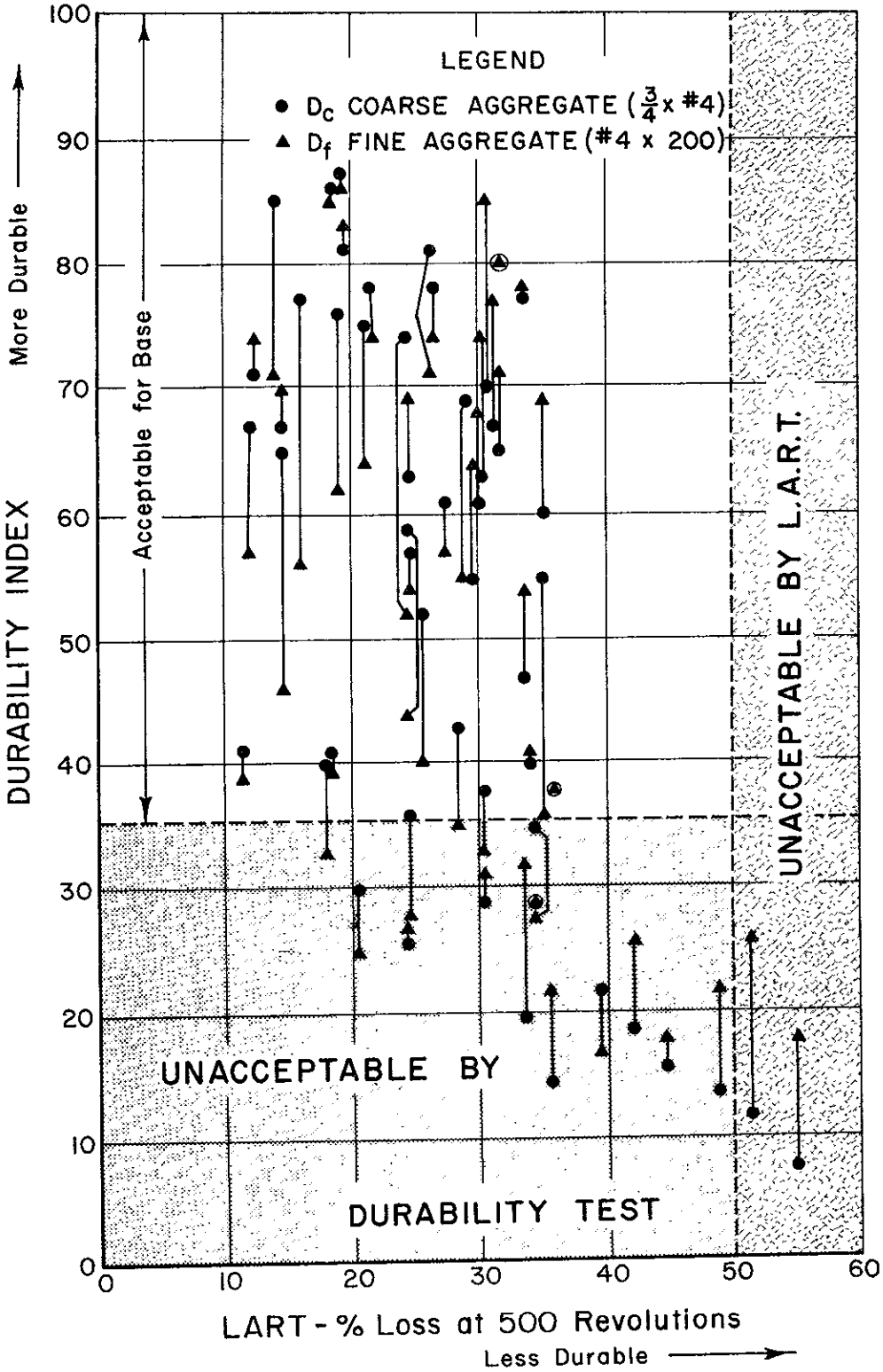

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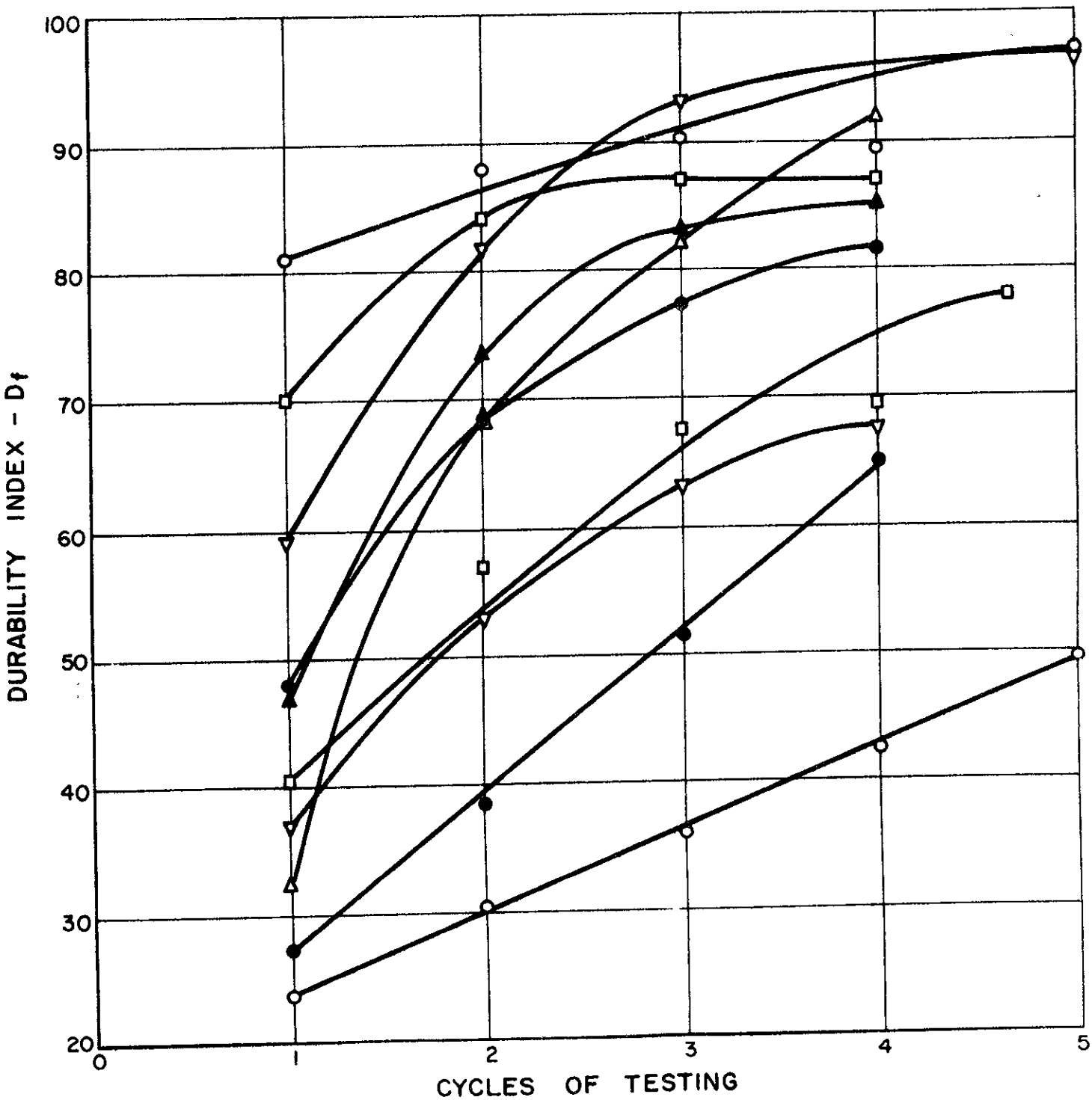
FIGURE 23

INCREASE IN DURABILITY INDEX CAUSED BY VARIOUS CYCLES OF WASHING



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